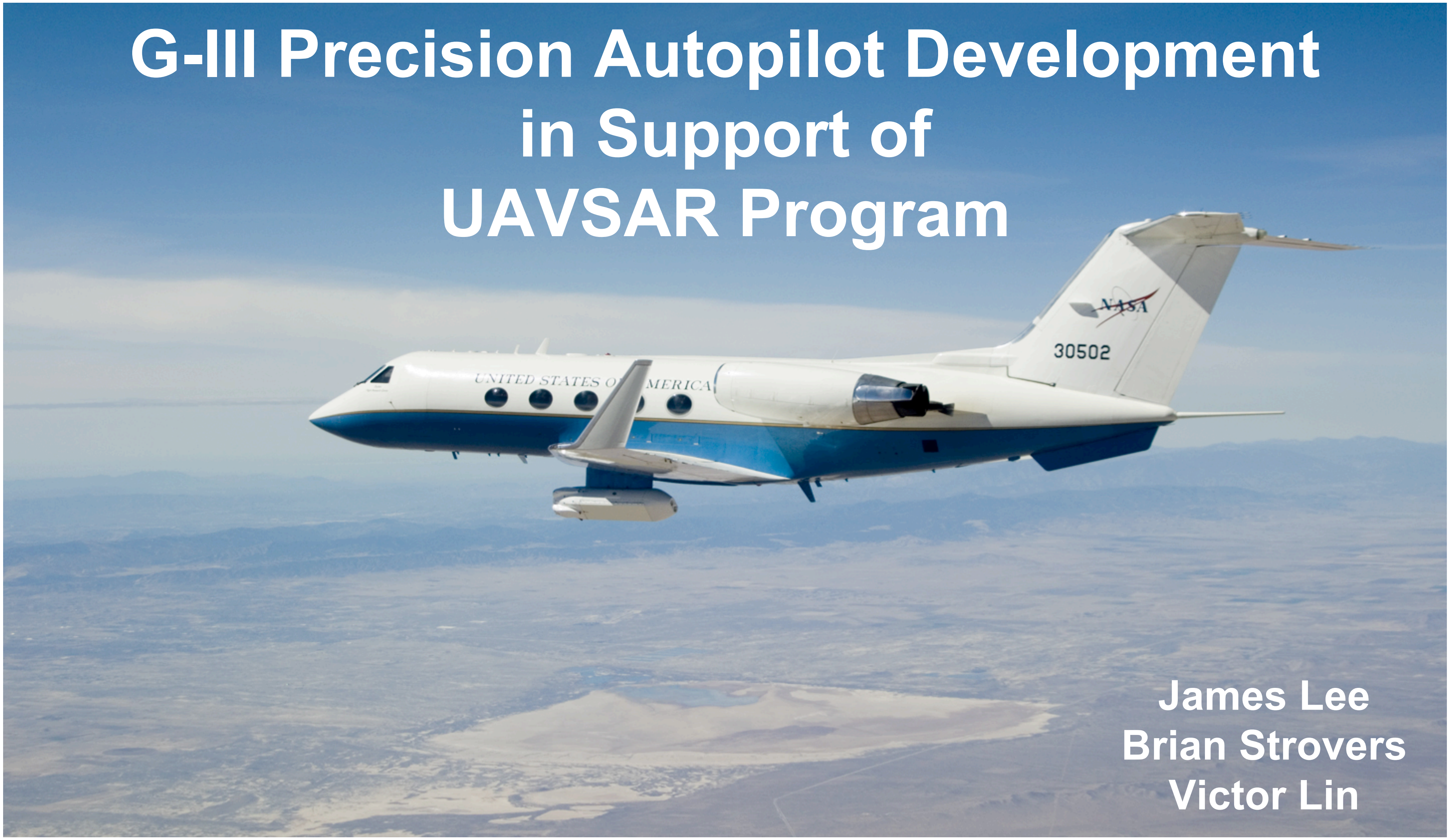
G-III Precision Autopilot Development in Support of UAVSAR Program



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UAVSAR

- **The primary objective of the UAVSAR Project is to:**
  - Develop a miniaturized polarimetric L-band synthetic aperture radar (SAR) for use on an unmanned aerial vehicle (UAV) or minimally piloted vehicle

- *JPL*
  - Designed, fabricated, and will operate the radar instrument
  - Conduct data analysis

- *Dryden Flight Research Center*
  - Provide RPI (Repeat Pass Interferometry) interim platform (NASA G-III) and head up flight operations
  - Develop Platform Precision Autopilot (PPA) capability

- **First Flight of SAR on G-III expected Fall 2007**

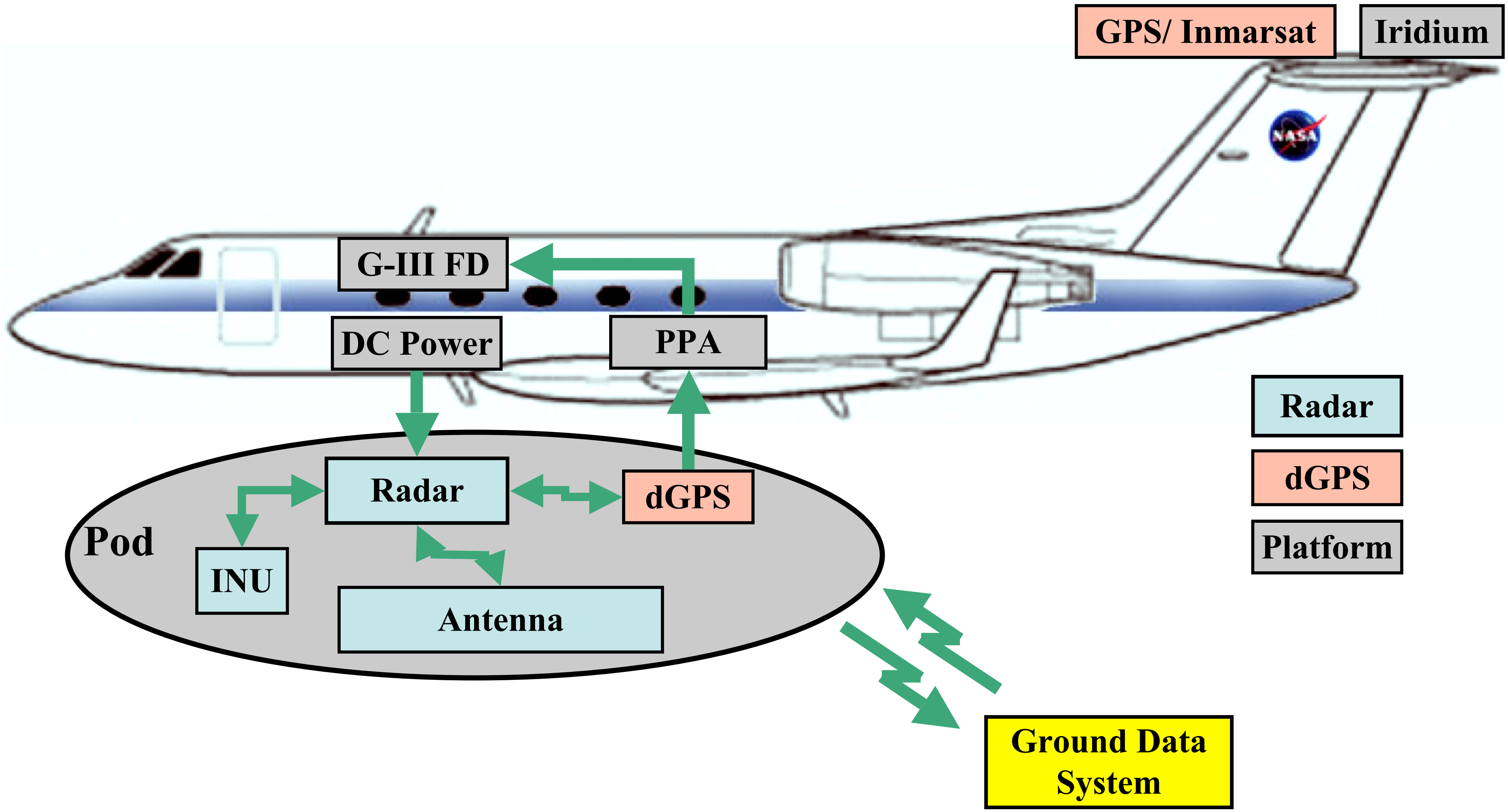
NASA Dryden's G-III Aircraft

- **Aircraft Dimensions**
  - Wing: span 77 ft 10 in; area 934.6 ft^2
  - Fuselage and tail: length 83 ft 1 in; height 24 ft 4.5 in
  - Large Internal Volume (1500 cu. Ft.)

- **Aircraft Performance**
  - Max Mach – 0.85
  - Max Operating altitude – 45Kft
  - Typical Cruise – 400 to 500 kts
  - Max Range – ~3000 nautical miles
  - Climb Rate – up to 4,000 fpm

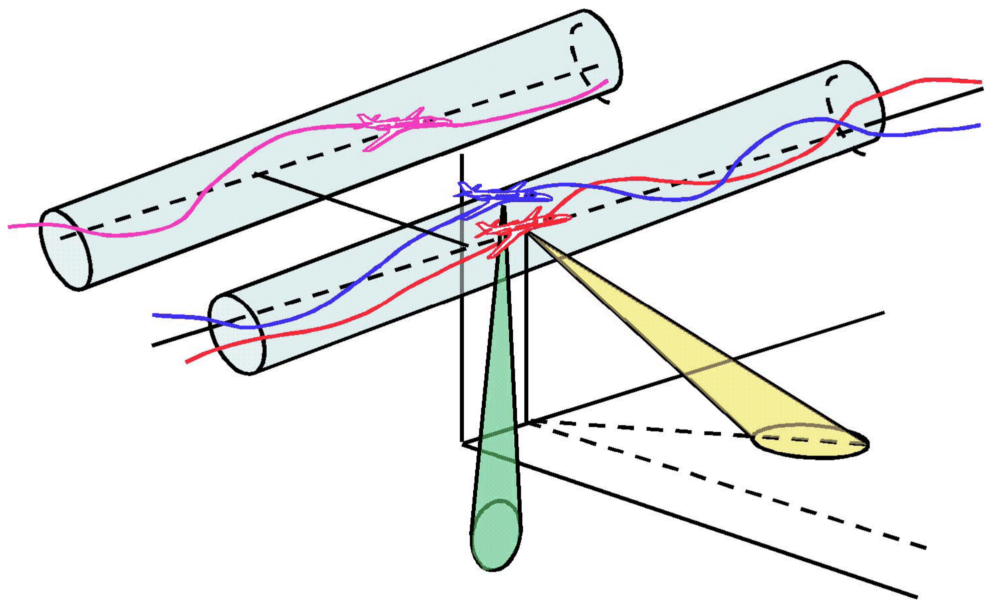
- **Aircraft Instrumentation**
  - Control surface positions
  - Flight Director
  - Air Data Computer
  - INS
  - Aircraft GPS
  - On-board experiments

UAVSAR High Level System Architecture



Platform Precision Autopilot (PPA) Requirements

- **Performance Requirements**
  - *The PPA shall fly the G-III within a 10 m (32.8 ft) diameter tube for at least 90% of each data take in conditions of calm to light atmospheric disturbances, as defined in MIL-STD-1797.*
  - *Minimize motion during data collection*
    - For best imaging, it is important to operate on a steady platform.



PPA Development Plan

- **Design Approach**

  - **Software is designed to be flexible with uploadable parameters**
    - Algorithms are developed and tested in Matlab/Simulink
    - Simulink models are auto-coded and ported to the host computer
    - Software development efforts are geared toward developing tools to allow for rapid software updates.
      - Navigation, guidance, and controller algorithms are refined based on flight test data

  - **The final version will include the following features:**
    - **Automation of parameters currently manually entered**
      - Built-in gain tables (transparent to user)
      - Biases and scale factors
    - **Enhanced safety features**
      - Prevent inadvertent engagement of controller outside flight envelop
      - Alert operator to internal faults, invalid navigation data, etc.
    - **Improved user-interface**
      - Read in JPL course file
      - Allow selection of different courses

PPA Development Flight Test Plan

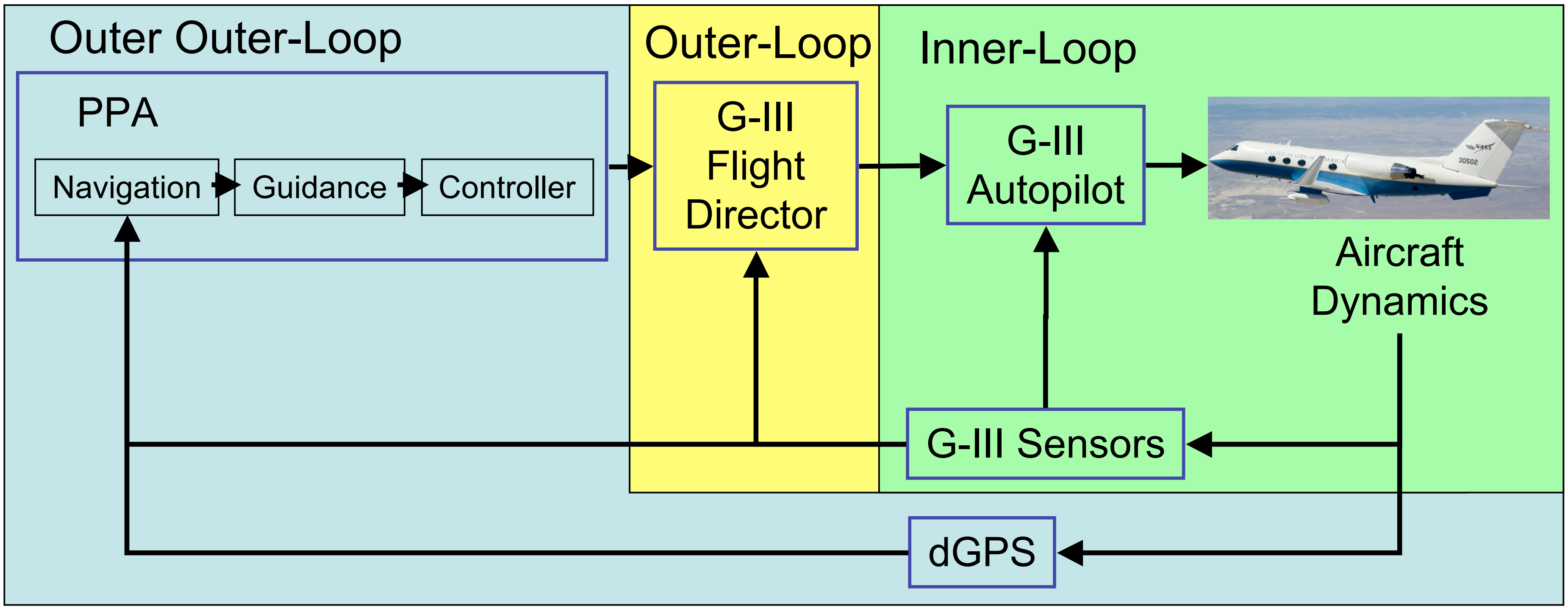
- **PPA Cycle I Controller Test Flights**
  - Description: Initial flight test of closed-loop PPA
  - Objective: Demonstrate closed-loop operation of PPA
    - Secondary Objective of demonstrating 10 m tube performance
  - Currently, near completion
  - Results shown later in presentation

- **Cycle II Controller Test Flights**
  - Description: Flight test of revised PPA applying lessons learned from previous flights.
  - Objective: Demonstrate PPA performance with an expanded flight envelope.

- **Cycle III Controller Test Flights**
  - Description: Flight test of revised PPA
  - Objective: Demonstrate operation of PPA to the customer (JPL).

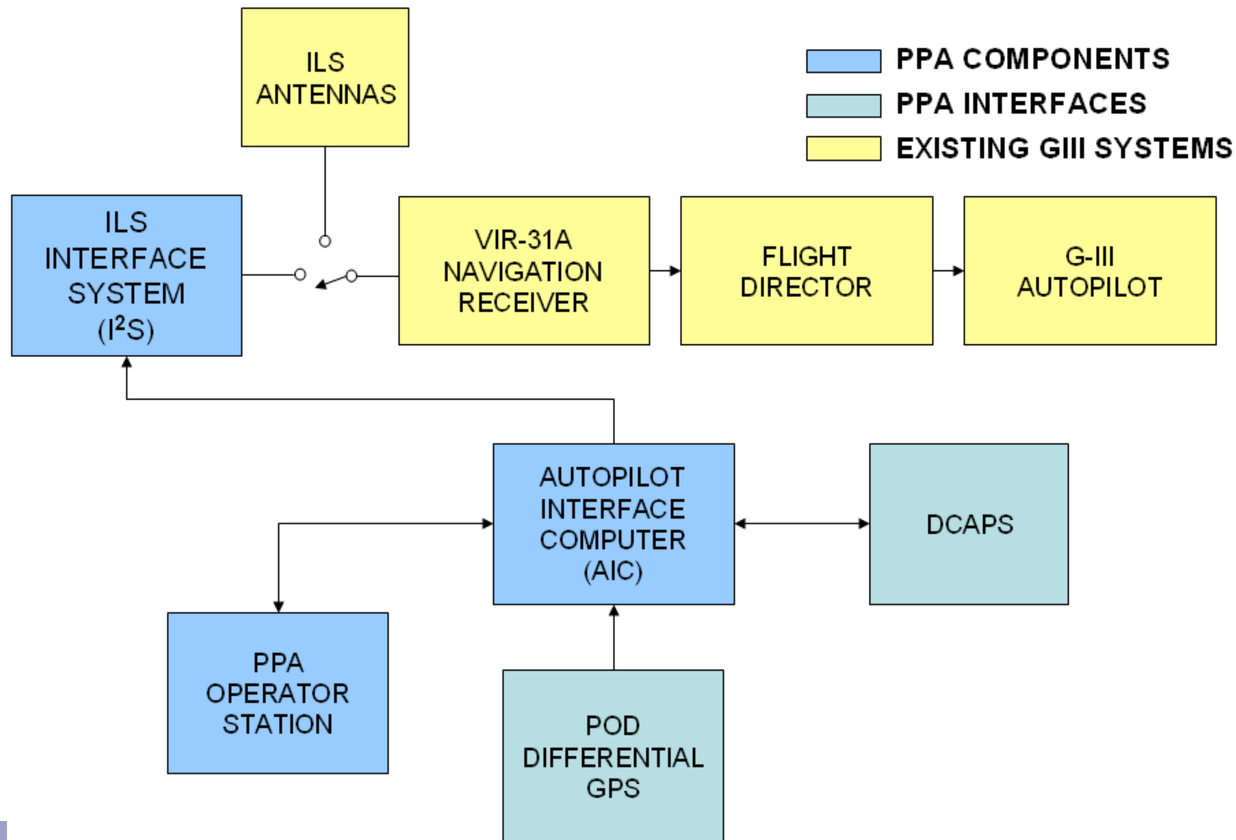
PPA Control Loop Visualization

- **PPA provides Outer Outer-Loop Control**
- **Aircraft Outer Loop controlled by G-III Flight Director**
- **Aircraft Inner-Loop dynamics stabilized by G-III Autopilot**

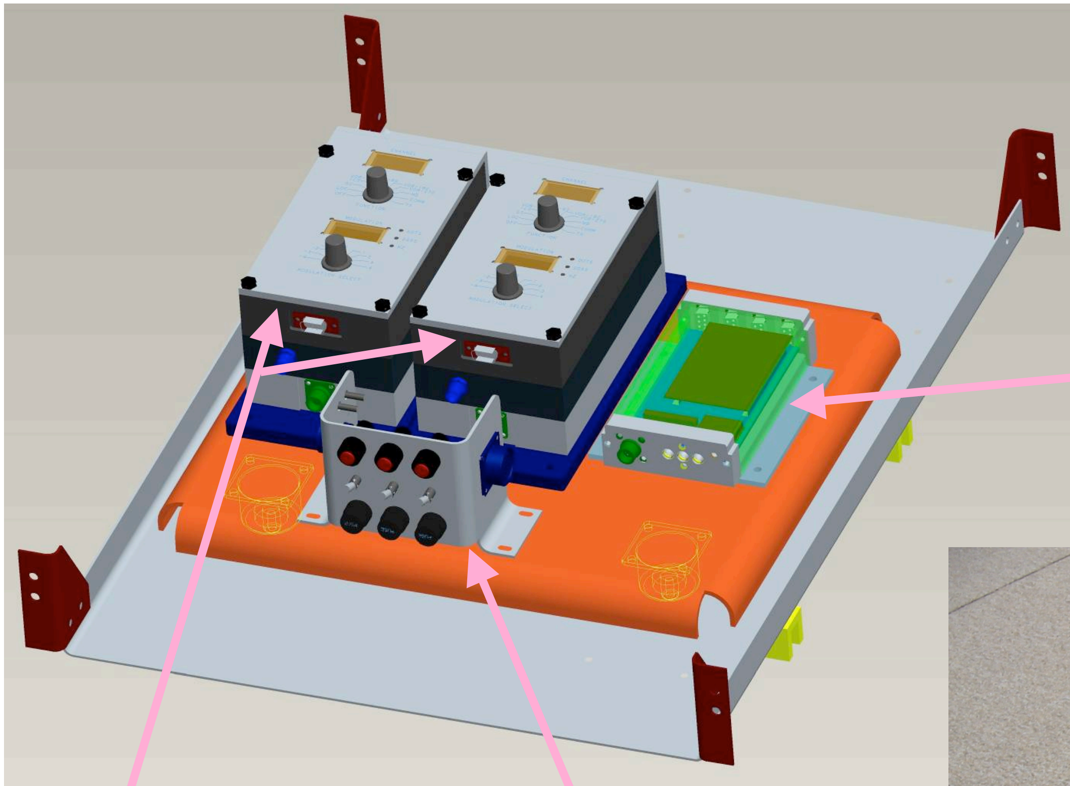


Motivation for Hardware Architecture

- **To minimize the impact on the GIII certification, the project elected to input signals through the Navigation Receiver to the Flight Director and baseline G-III Autopilot**
- **Advantage:**
  - Preserves the safety limits of the G-III Flight Director and G-III Autopilot
- **Challenges:**
  - Navigation Receiver
    - Modulated RF (I^2S)
    - Noise, scaling, & offsets
  - Flight Director
    - Additional inputs determine output
    - Variable scaling of inputs
    - Variable rate limits



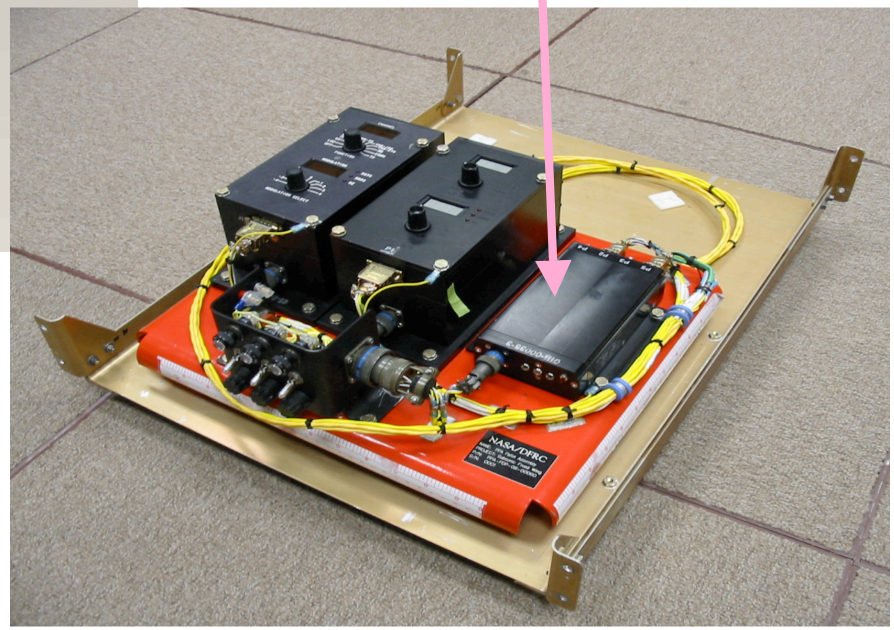
PPA Pallet on Experiment Rack



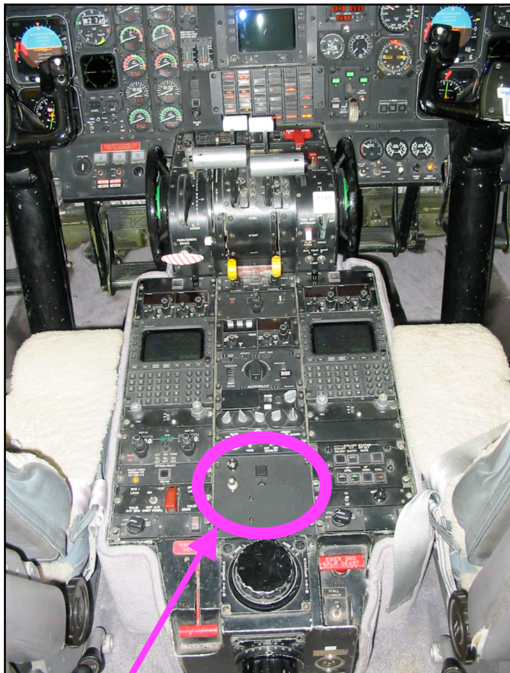
Autopilot
Interface
Computer

ILS
Interface
System

Power
Distribution
Panel

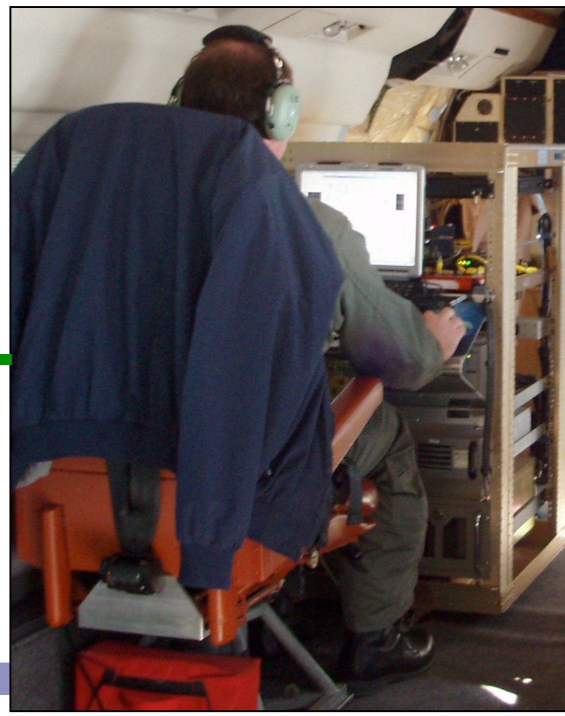


Aircraft Configuration with PPA



PPA Enable Switch

PPA Station (Operator Station, AIC, I2S, & dGPS)

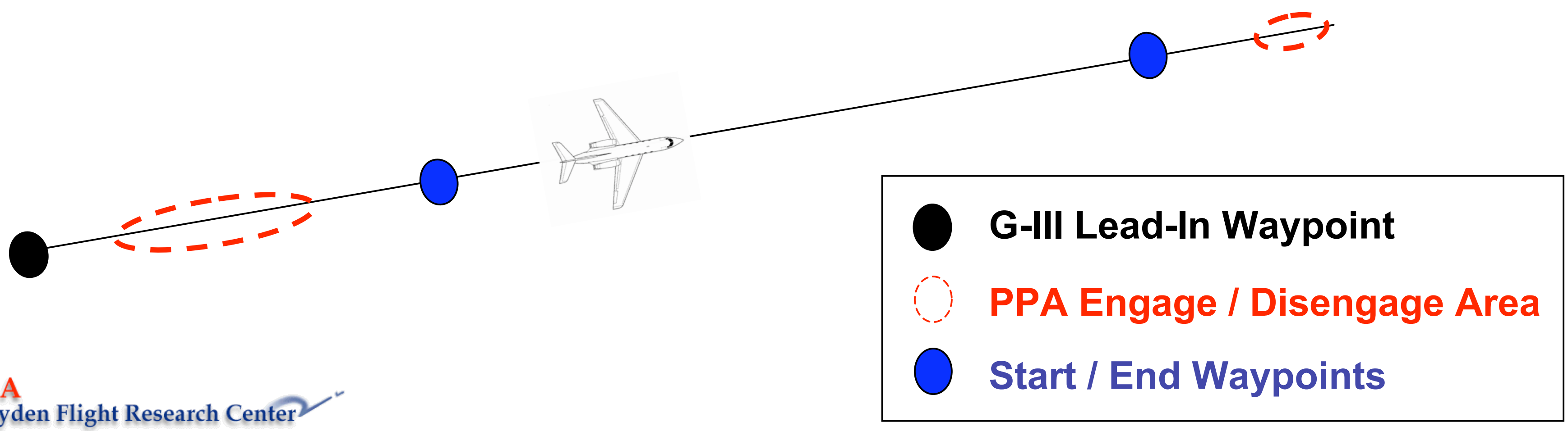


DCAPS Station

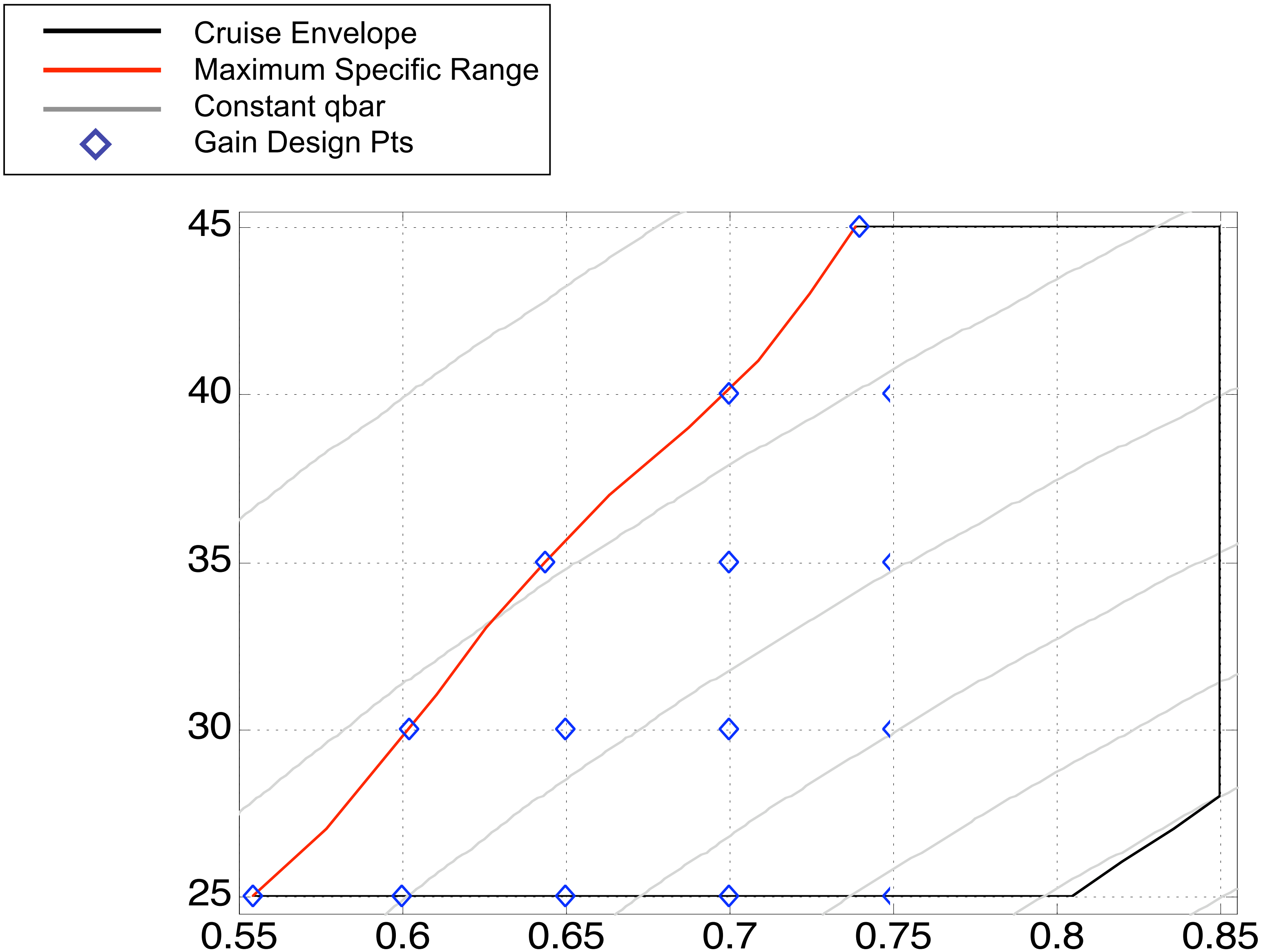
PPA Operator Station

Anticipated Courses

- Courses
  - Distance between start and end waypoints up to 200 km
  - All headings
  - Within few degrees of poles
  - Cross equator and prime meridian
  - Constant heading or great earth circle
  - GPS or pressure altitude
  - Pilot flies aircraft near the segment between the lead-in and start waypoints
    - Navigation guidance from PPA operator
- Operator will determine when to engage PPA during flights

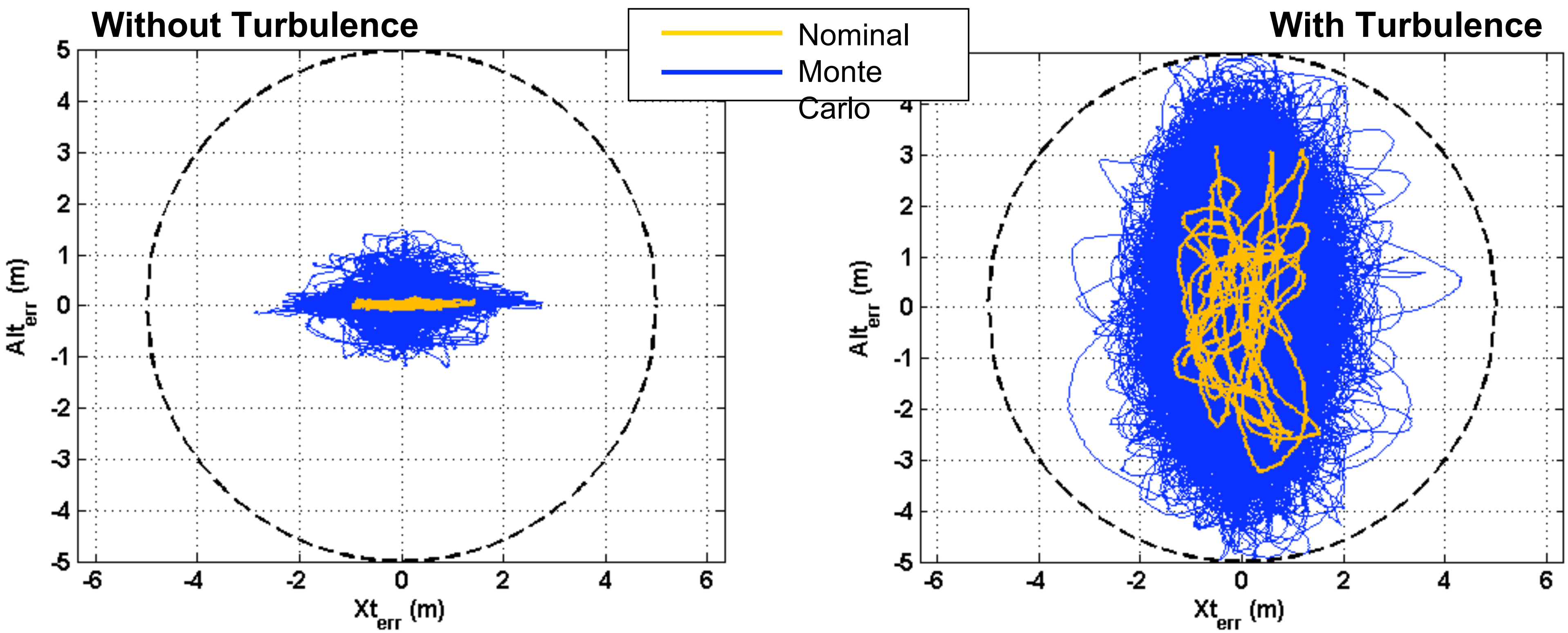


PPA Planned Flight Envelope



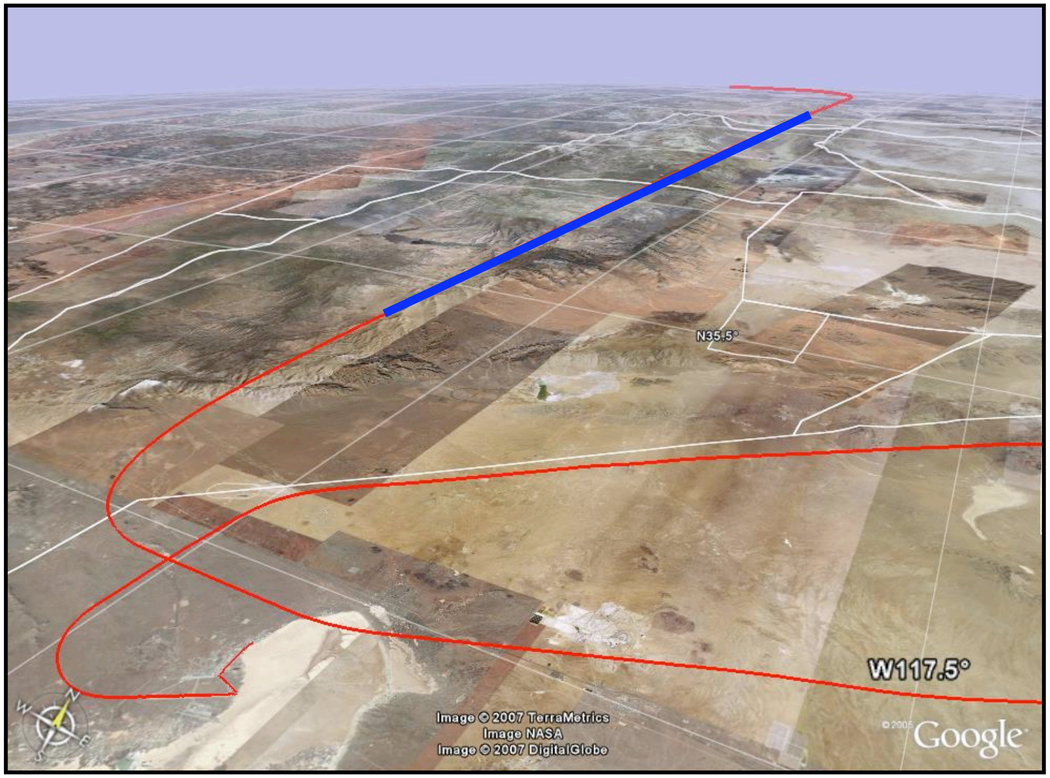
Monte Carlo Simulation Results
10 m. Tube Performance

- **Monte Carlo analysis conducted with GIII simulation**
  - Consists of randomly perturbing simulation parameters within specified bounds.
    - Approximately 45 simulation parameters perturbed including: aerodynamics, mass properties, system timing, winds.
    - 500 simulation runs were conducted at each specific flight condition.
      - With and without light turbulence



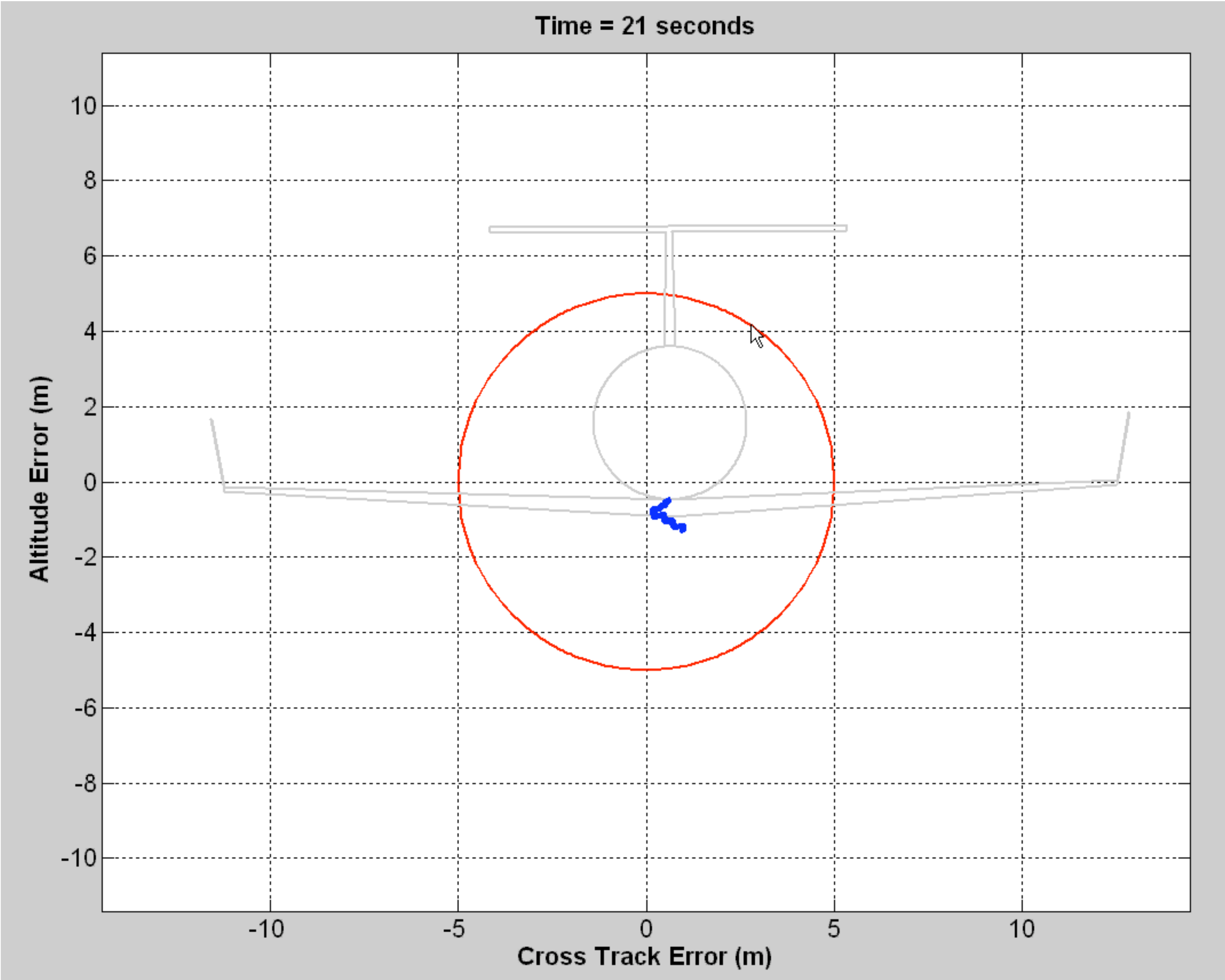
Initial Flight Test Results

- Cycle 1 PPA Flight #5 – 14 May 2007
  - Fourth closed loop flight
  - 35,000 ft – Mach 0.75
  - Light turbulence
  - Northbound course



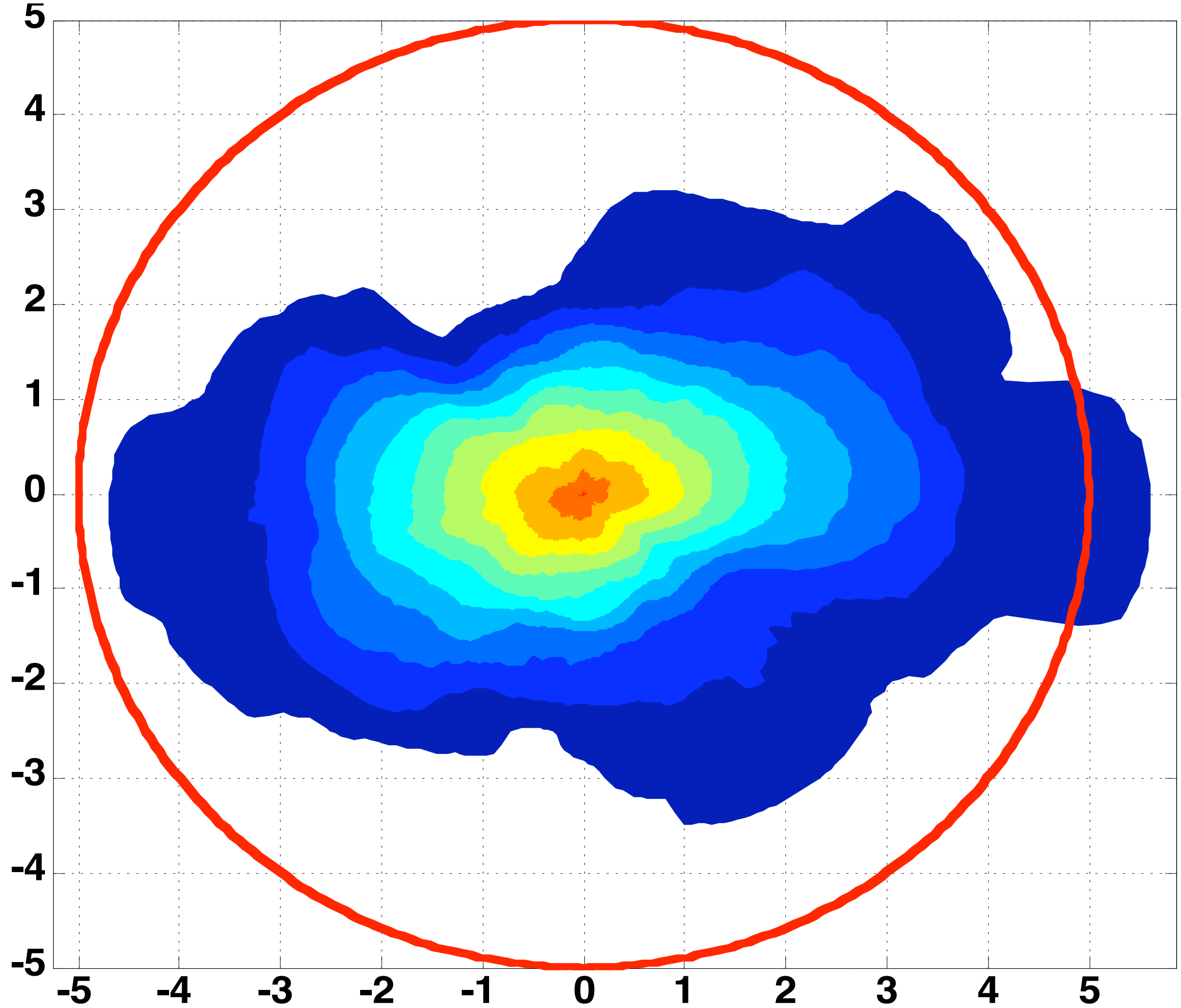
Cycle 1 PPA Flight #5 – 14 May 2007

Cycle 1 PPA Flight #5 – 14 May 2007



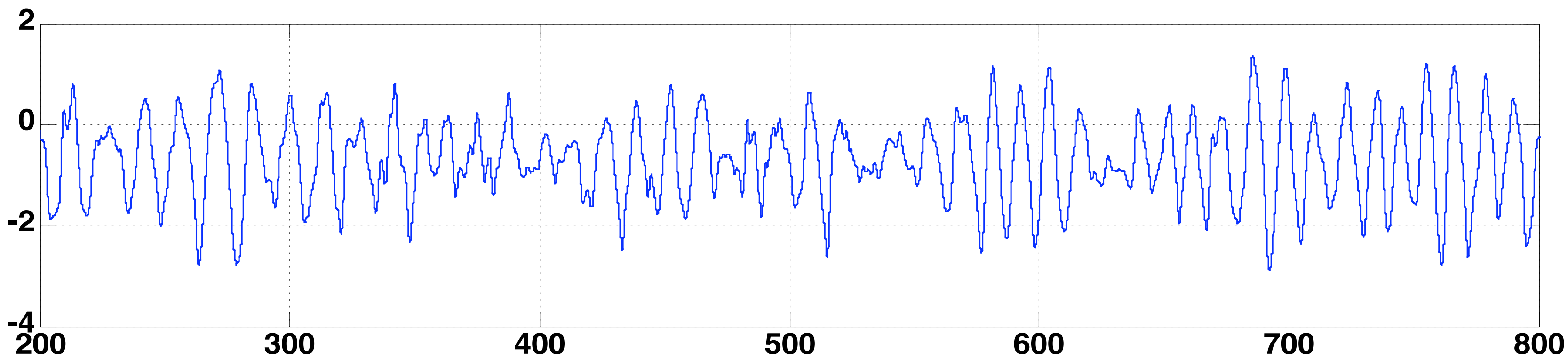
Flight Data Results
10 m. Tube Performance

- Cycle 1 PPA Flight #5 – 14 May 2007
- Total Time Tracking in Ten Meter Tube = 580 sec
- dGPS Altitude
- Geodetic Course



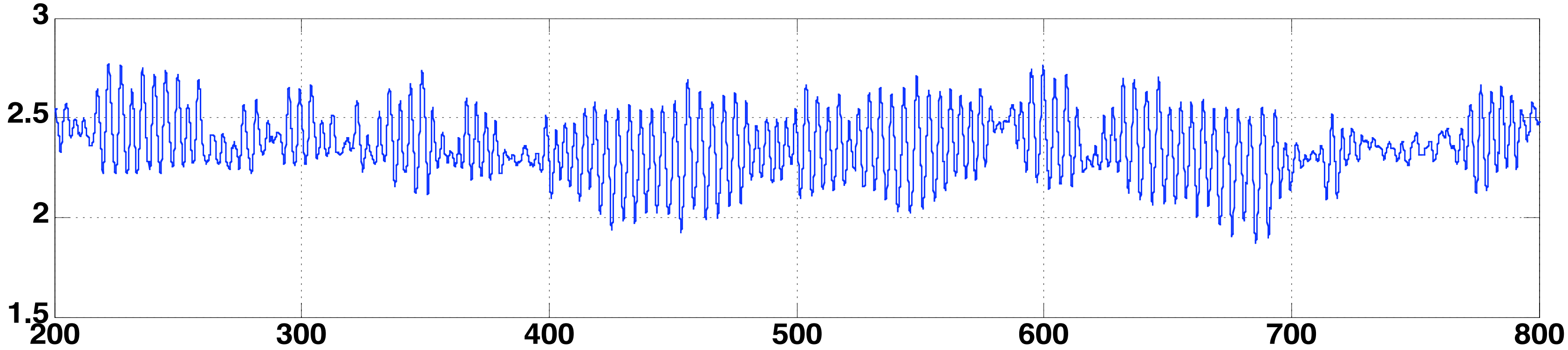
Flight Data Results

- JPL Desired Aircraft Euler Angles and Rates
  - Maximum angular variation for a 200 km run:
    - Roll Angle: 5 deg
  - Maximum angular rates:
    - Roll Rate: 1 deg/s



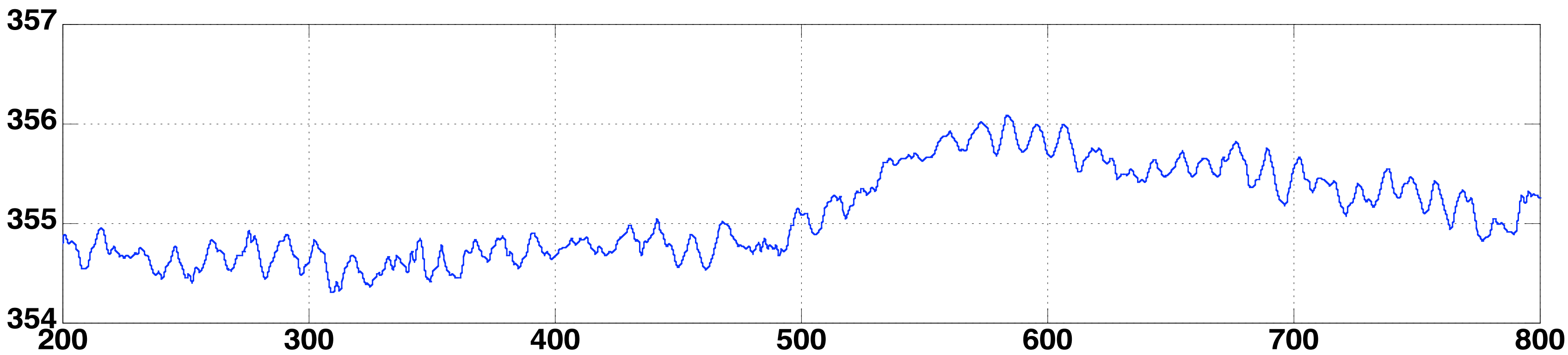
Flight Data Results

- JPL Desired Aircraft Euler Angles and Rates
  - Maximum angular variation for a 200 km run:
    - Pitch Angle: 5 deg
  - Maximum angular rates:
    - Pitch Rate: 0.45 deg/s



Flight Data Results

- JPL Desired Aircraft Euler Angles and Rates
  - Maximum angular variation for a 200 km run:
    - Yaw Angle: 15 deg
  - Maximum angular rates:
    - Yaw Rate: 0.45 deg/s



Repeat Pass Trajectories

- Cycle 1 PPA Flight #5 – 14 May 2007
  - Repeat pass trajectories
  - Fourth closed loop flight
  - 35,000 ft – Mach 0.75
  - Light turbulence
  - East-West course

Repeat Pass Trajectories

Conclusions

- **Five Cycle 1 precision autopilot flights have been completed as of May 14, 2007**
  - First flight was open-loop controller
  - Second, third, fourth, and fifth flights were closed loop
    - Fifth flight demonstrated increasing duration within ten meter tube (approximately 90% of the time in the ten meter tube over a 200km course)

- **Additional Work:**
  - Expand flight envelope in Cycle II
  - Further refinement of Navigation, Guidance, and Control algorithms
  - User-friendly interface and customer tailoring for Cycle III

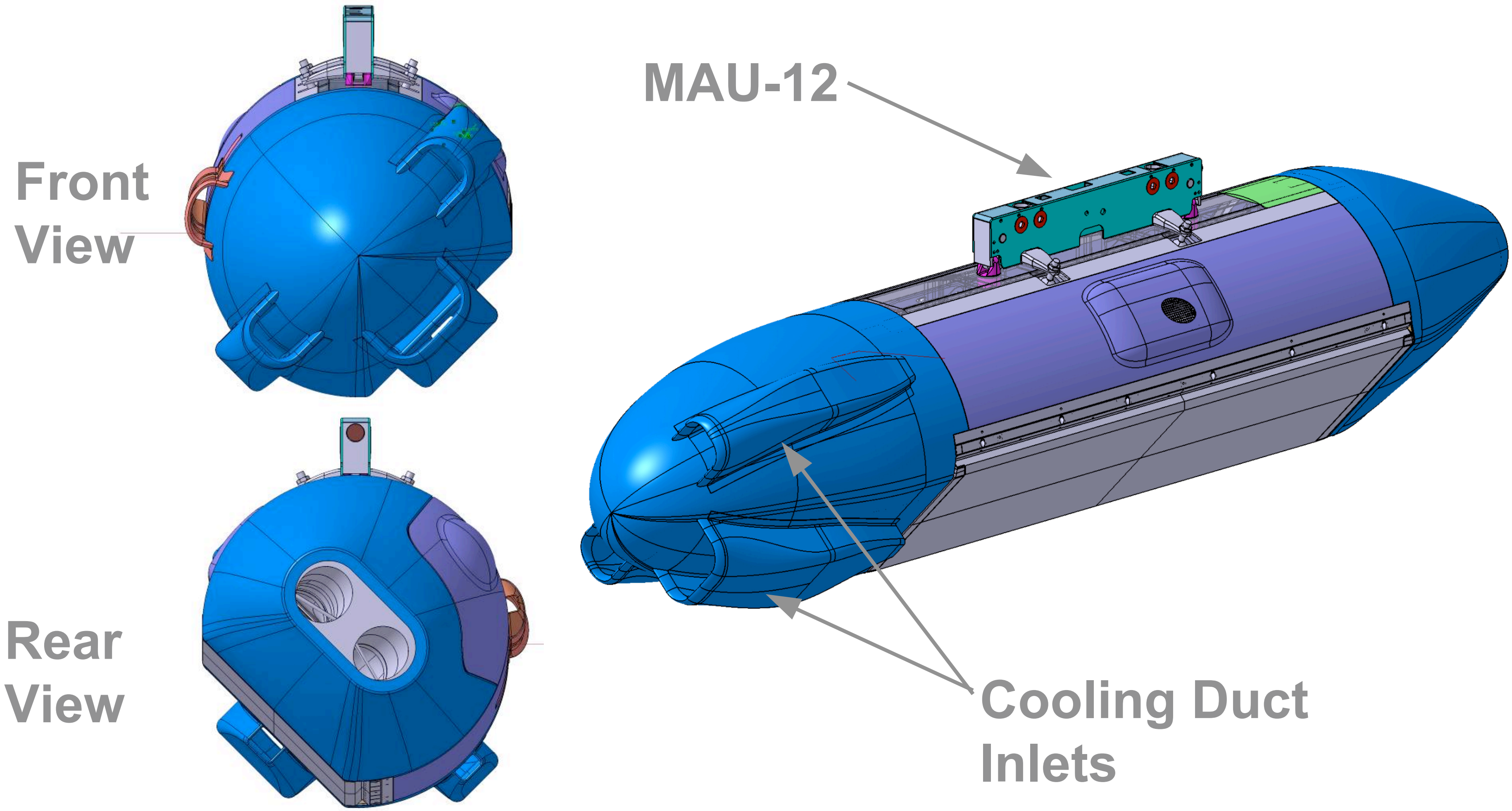
Questions?

Backup Slides

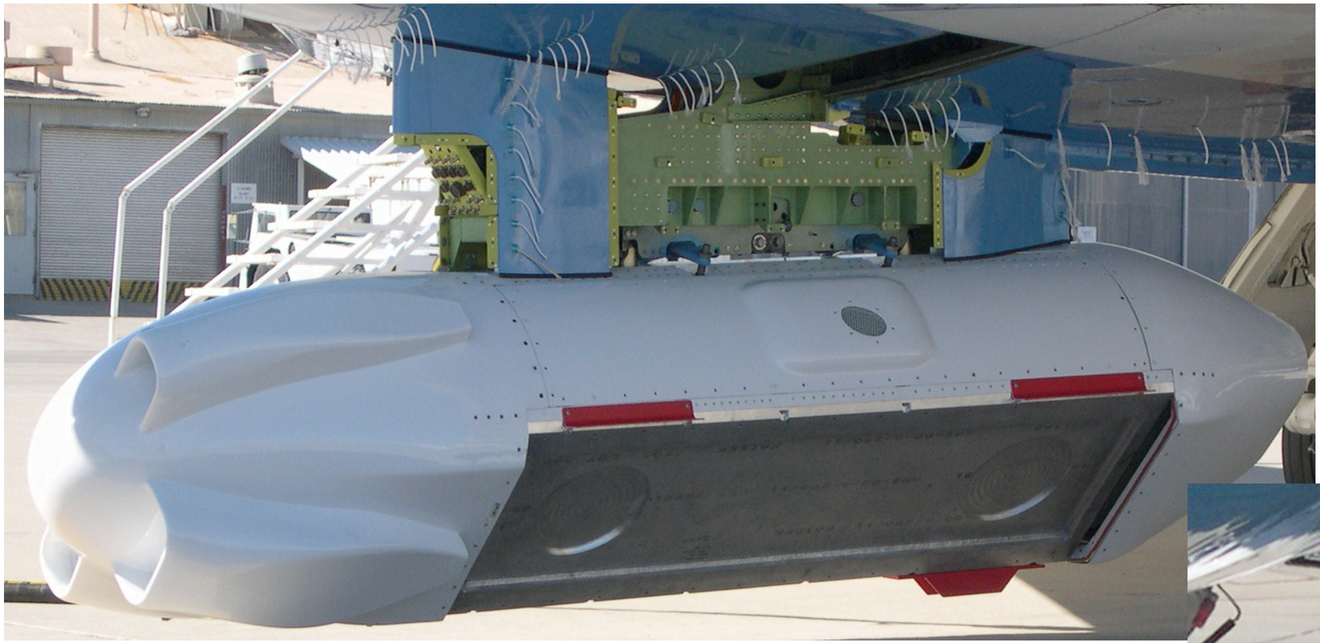
Global DGPS, Inmarsat, & Iridium

- **Differential GPS**
  - Developed by JPL
  - Provides Earth Centered Earth Fixed (ECEF) positions in meters
  - 1 Hz update rate
- **Inmarsat**
  - Three Inmarsat geosynchronous communication satellites are used to relay GPS correction messages on their L-band global beams.
- **Iridium**
  - Also, provides GPS corrections

Pod Design
External Views



UAVSAR Pod

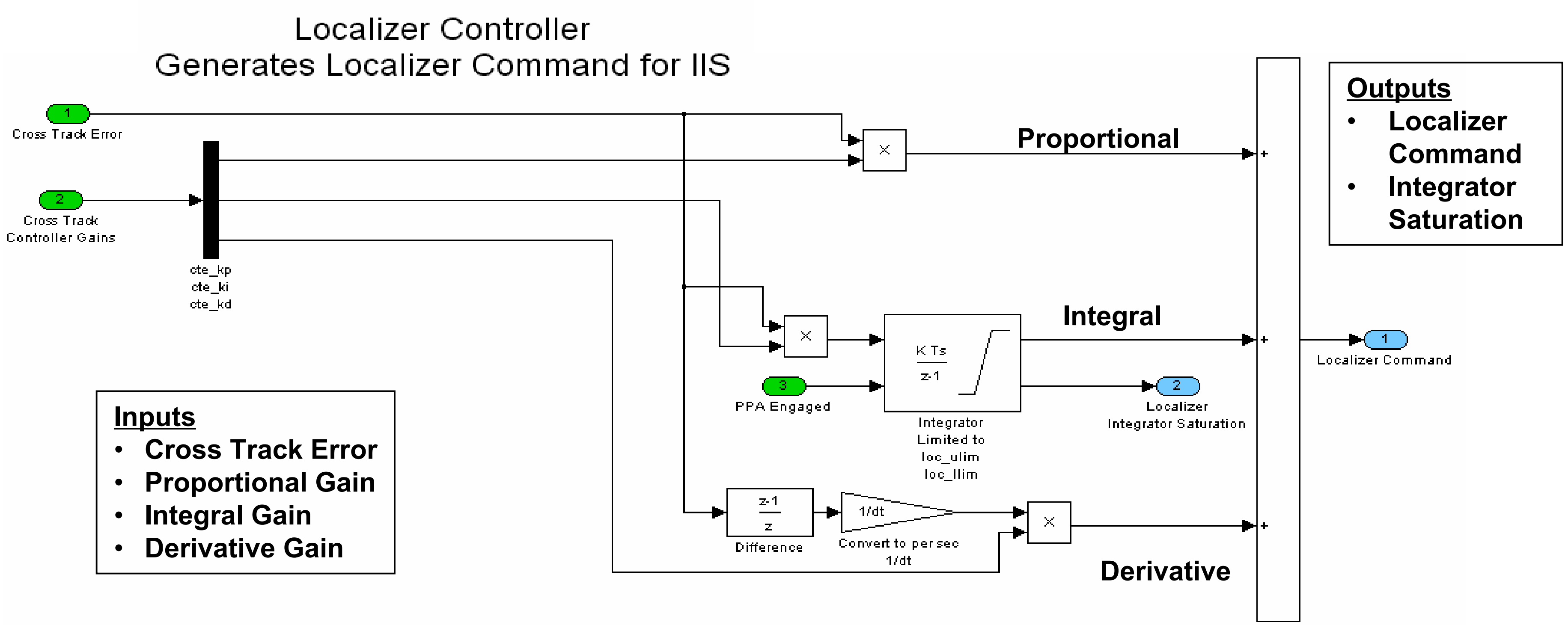


PID Controllers

- PID controller generates localizer and glideslope deviations sent to the G-III Flight Director via the G-III Navigation Receiver.

- Localizer & Glideslope Controllers share the same architecture.
  - Difference between the two is the Glideslope includes a vertical acceleration feedback loop

Basic Controller Architecture



PPA Hardware Subsystems

- **Autopilot Interface Computer (AIC)**
  - Hosts the PPA guidance, navigation, and control algorithms
  - Interface to external digital data sources
    - G-III navigation data via DCAPS from G-III ARINC 429 bus
    - Differential GPS from dGPS in radar pod
  - Output commands to I^{2}S
  - Interface to operator station for waypoint, reference, gain input, and AIC telemetry

- **ILS Interface System (I^{2}S)**
  - Modulates the ILS control signal based on input from AIC
  - Provides the ILS glideslope (GS) and localizer (LOC) RF signals

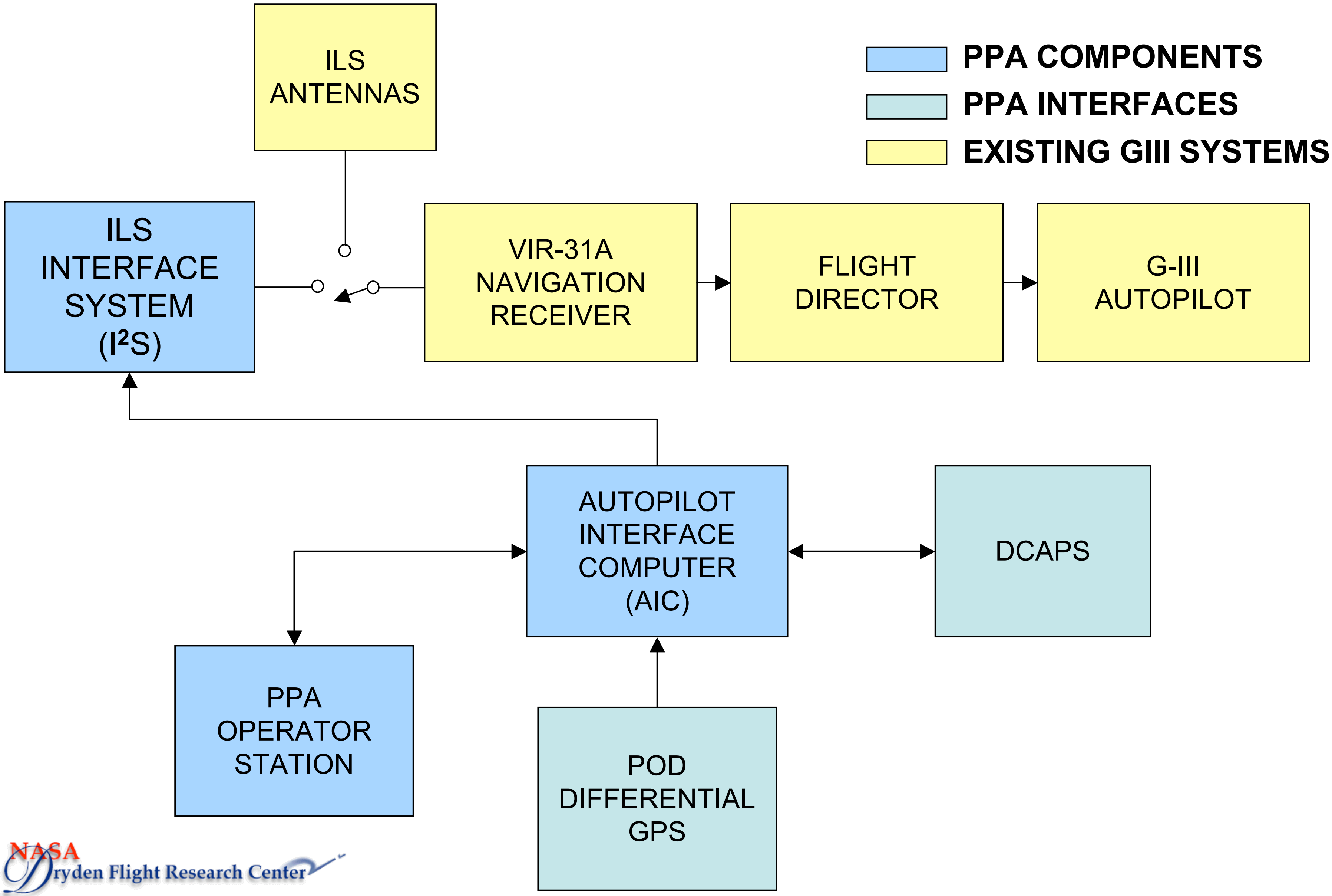
PPA Hardware Subsystems (cont.)

- **Operator's Station**
  - Display status and performance information in flight
  - Record the telemetry data (entire PPA input/output plane)
  - Upload gains, waypoints, altitude
  - Command navigation initialization and error status reset
  - Command PPA engage and disengage

- **RF Switches**
  - Select between baseline external ILS antennas and the I^2S signal

- **Power Distribution Panel (PDP)**
  - Fuse protection for PPA components
  - Power control for PPA components

PPA Hardware Interfaces



Instrument Landing System

- ILS consists of two radio transmitters each with a signal at 90 Hz and 150 Hz
  - VHF transmitter for Localizer
  - UHF transmitter for Glideslope

- Localizer and Glideslope receivers on aircraft measure Difference in Depth Modulation (DDM) of the 90Hz and 150 Hz signals.
  - DDM of localizer signal indicates if aircraft is left or right of centerline
  - DDM of glideslope signal indicates if aircraft is above or below glideslope
  - DDM of zero indicates aircraft is along centerline or glideslope